6.012 Microelectronic Devices and Circuits
Spring 2007

May 21, 2007
Final Exam
(200 points)
-OPEN BOOK-

	Problem #points
NAME________________________________	1__________
RECITATION TIME_________________________	2__________
	3__________
	4__________
	5__________
	Total__________

General guidelines (please read carefully before starting):

- Make sure to write your name on the space provided above.
- This exam is open book. You can use any material you wish, except for computers.
- All answers should be given in the space provided. Please do not turn in any extra material.
- You have 180 minutes to complete the quiz.
- Make reasonable approximations and *state them*, i.e. low-level injection, extrinsic semiconductor, quasi-neutrality, etc.
- Partial credit will be given for setting up problems without calculations. NO credit will be given for answers without reasons.
- Use the symbols utilized in class for the various physical parameters, i.e. N_a, τ, ε, etc.
- Every numerical answer must have the proper units next to it. Points will be subtracted for answers without units or with wrong units.
- Use the following fundamental constants and physical parameters for silicon at room temperature.

$n_i = 1.0 \times 10^{10}\ cm^{-3}$
$kT/q = 0.025V$
$q = 1.6 \times 10^{-19}\ C$
$\varepsilon_s = 1.0 \times 10^{-12}\ F/cm$
$\varepsilon_{ox} = 3.45 \times 10^{-13}\ F/cm$

1. (35 points)

Figure 1(a) is a common emitter amplifier circuit with a Bipolar Junction Transistor (BJT).

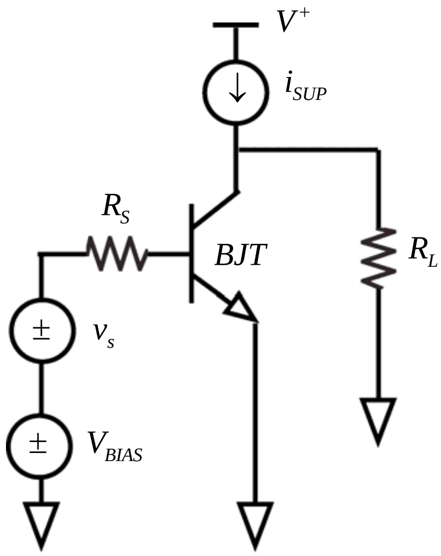


Figure 1(a)

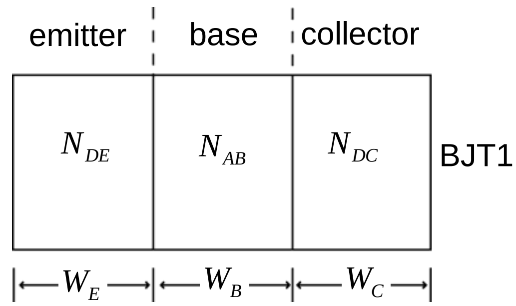


Figure 1(b)

The dimensions and doping concentration of this BJT are indicated in Figure 1(b). We will call this transistor BJT1 and its small signal circuit related parameters are labeled ($r_{\pi 1}$, g_{m1}, $C_{\pi 1}$, $C_{\mu 1}$, r_{o1}, etc.). For this problem, assume $C_{\pi} \approx g_m \tau_F$.

Assume recombination/generation can only occur at the contacts of the BJTs.

(a) Draw the small signal circuit model for the circuit in Figure 1(a). Label $g_{m1}, r_{\pi 1}, C_{\pi 1}, C_{\mu 1}, r_{o1}$.

(b) If BJT1 is used in the amplifier and the current i_{SUP} doubles, obtain the ratio of parameters (1) to (5).

(1) g_{m2x} / g_{m1}

(2) $r_{\pi 2x} / r_{\pi 1}$

(3) $C_{\pi 2x} / C_{\pi 1}$

(4) $C_{\mu 2x} / C_{\mu 1}$

(5) r_{o2x} / r_{o1}

Figure 1(c) is the schematic diagram of another BJT, (BJT2). BJT2 has the same dimensions and doping level as BJT1, except half of the emitter region is replaced with polySi. The carrier mobility in the polySi is 20 times less than the mobility in the single crystalline emitter region, while all other parameters remain the same. The purpose of the polySi in the emitter region is to enhance the forward active current gain $\beta_F = \frac{I_C}{I_B}$.

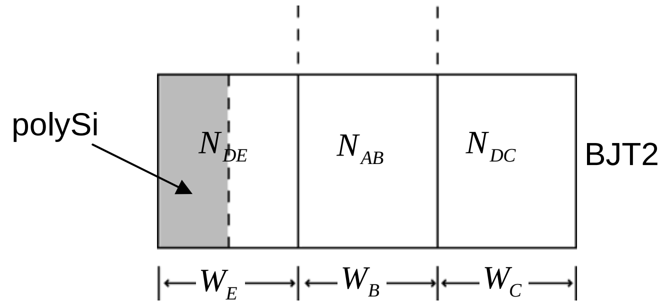
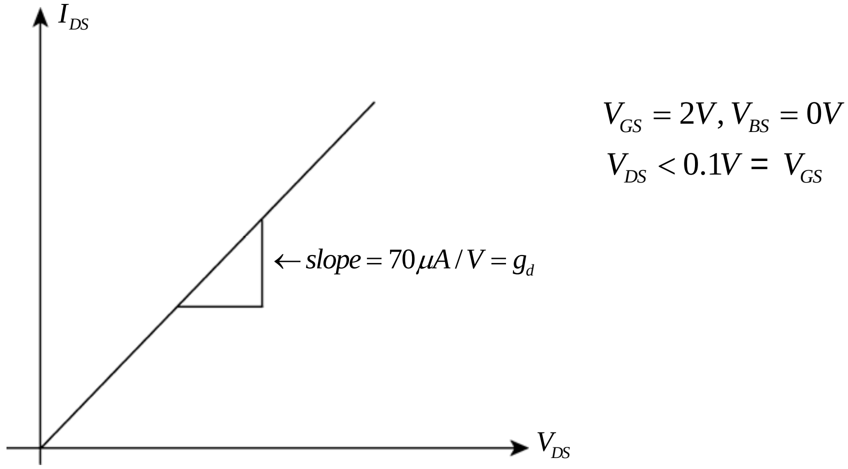


Figure 1(c)

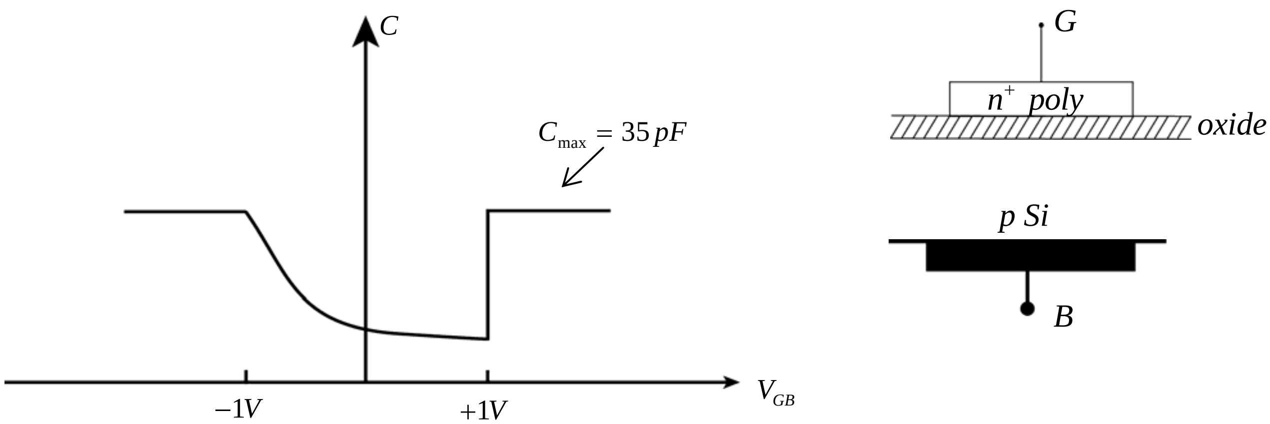
(c) Obtain the ratio of β_{F2} / β_{F1}.

2. (45 points)

You are given the following I-V characteristic for an N-MOSFET with $W = L = 100\,\mu m$, measured at $V_{GS} = 2V$ and V_{DS} = V_{GS}:



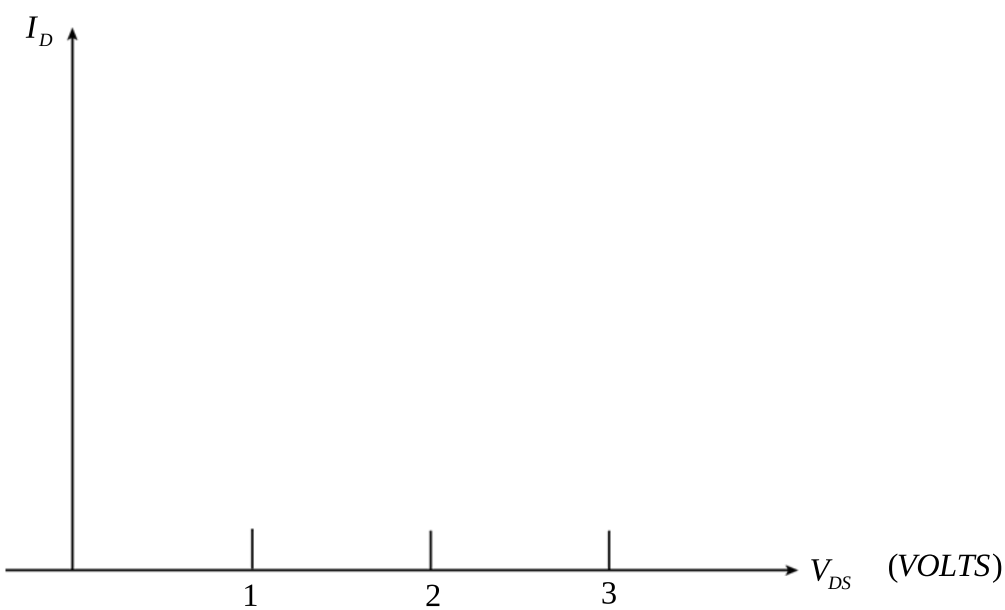
MOS capacitors fabricated on the same substrate as the N-MOSFETs, with the same n^+ polysilicon gate material, gate oxide thickness, and substrate doping, and an area of $100\,\mu m \times 100\,\mu m \left(10^{-4}\,cm^2\right)$, show the following C-V characteristic:



(a) Find the oxide capacitance per unit area, C_{ox}, and the threshold voltage, V_{Tn}, for the N-MOSFET.

(b) Derive an expression for the electron mobility, μ_n, in the MOSFET in terms of the slope, g_d, and the other parameters given above. Calculate μ_n numerically.

(c) Sketch I_D vs. V_{DS} on the axes below, for $V_{GS} = 2V, V_{BS} = 0V$, for the N-MOSFET. Label the values of the saturation voltage, $V_{DS_{sat}}$, and current, $I_{D_{sat}}$. Label the regimes of operation.

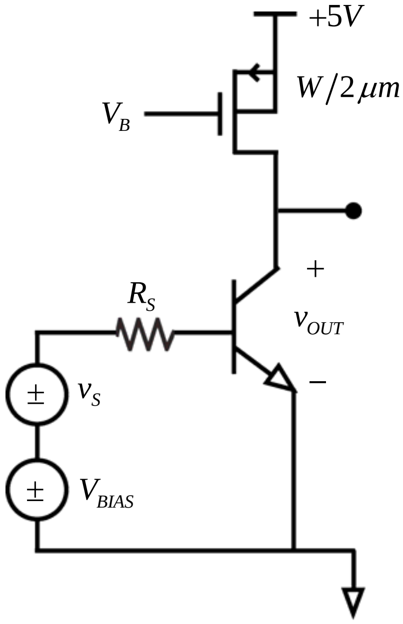


(d) Calculate the electron velocity at the source end of the channel ($v_y(y=0)$) and at the drain end of the channel ($v_y(y=L)$), for $V_{GS} = 2V, V_{DS} = 0.5V, and\ V_{BS} = 0V$.

(e) The value of V_{BS} is now changed to $-3V$. Calculate the new values for $V_{DS_{sat}}$ and $I_{D_{sat}}$ for $V_{GS} = 2V$ and $V_{BS} = -3V$, assuming that the substrate doping is $N_a = 10^{17} cm^{-3}$.

3. (40 points)

You are given a common emitter amplifier with $R_L \to \infty$ shown below.



MOS Data

$V_{Tp} = -0.5V$

$\mu_p C_{ox} = 25\mu A / V^2$

$\lambda_p = 0.05V^{-1}$

Bipolar Data

$\beta_0 = 100$

$V_A = 20V$

$V_{CESAT} = 0.2V$

Assume $\lambda_p = 0$ for parts (a) and (b).

(a) Calculate the small signal open circuit voltage gain. Assume V_{BIAS} is set such that $I_{Dp} = I_C = 100\mu A$ and both devices are in their constant current operating region.

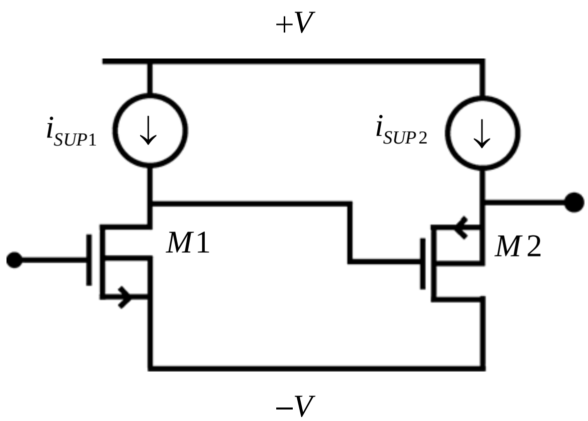
(b) Calculate V_B and W such that the output swing is between $0.2V$ and $4.5V$.

(c) Find R_{in}, R_{out} and A_{vo} for this amplifier.

(d) Calculate the open circuit voltage gain given $R_s = 75k\Omega$.

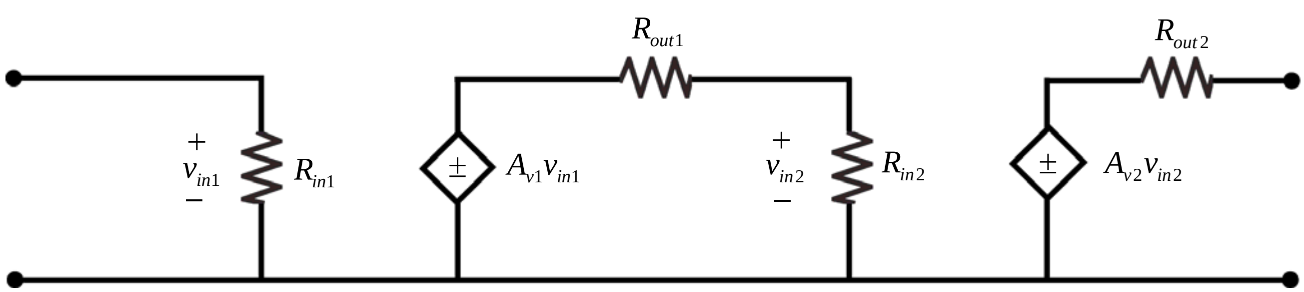
4. (40 points)

You are given a CS-CD voltage amplifier, with its two-port model shown below.



The bias conditions yielded

$R_{in1} \to \infty$	$A_{v1} = -100$	$R_{out1} = 100k\Omega$
$R_{in2} \to \infty$	$A_{v2} = 1$	$R_{out2} = 1k\Omega$



(a) Place and label capacitors $C_{gs1}, C_{gd1}, C_{db1}, C_{gs2}, C_{gd2}$ and C_{db2} on the two-port model diagram above. Hint: Label the G S D B on the two-port model for each transistor.

(b) Perform the Miller approximation on all capacitors that are coupling an output and input. Redraw the two-port model and simplify by adding capacitors in parallel. Place and label each capacitor and any applicable circuit parameters.

(c) Given $R_S = 1k\Omega$ and $R_L = 1k\Omega$, calculate the DC gain v_{out}/v_s for this two-stage amplifier.

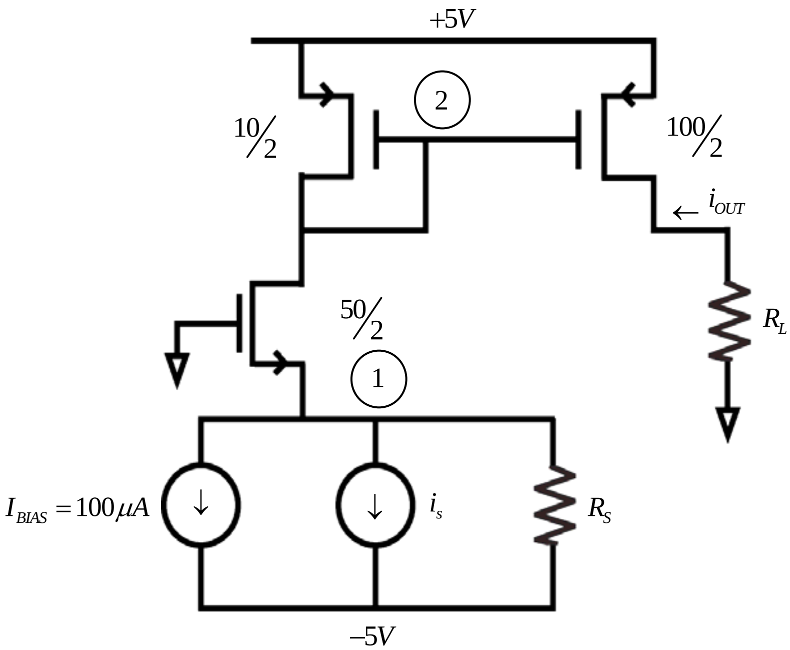
(d) Given

$$C_{gs1} = C_{gs2} = 100\,fF$$
$$C_{gd1} = C_{gd2} = 20\,fF$$
$$C_{db1} = C_{db2} = 20\,fF$$

use the open circuit time constant method to calculate ω_{3db}.

5. (40 points)

You are given a two-stage current amplifier that uses a common-gate stage followed by a common source stage. Assume all backgates are shorted to their respective sources.

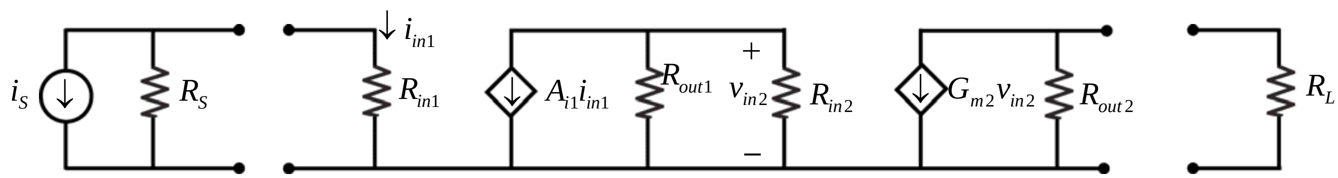


P – MOSFET	N – MOSFET
$V_{Tp} = -1V$	$V_{Tn} = 1V$
$\mu_p C_{ox} = 25\mu A/V^2$	$\mu_n C_{ox} = 50\mu A/V^2$
$\lambda_p = 0.1V^{-1}$	$\lambda_n = 0V^{-1}$

(a) Calculate the DC value I_{OUT}. You may assume all devices are saturated and $i_s = 0$ and $R_S \to \infty$ for this part.

(b) Calculate the DC voltages at node 1 and node 2. Ignore the signal source i_s and associated source resistance R_S and assume $R_L = 0$ for this calculation. Verify that all three transistors are saturated.

(c) Given the small signal two-port model for the CG-CS current amplifier shown below, calculate (1) thru (6).



(1) R_{in1}

(2) A_{i1}

(3) R_{out1}

(4) R_{in2}

(5) G_{m2}

(6) R_{out2}

(d) Given $R_s \to \infty \quad R_L \to 0$, calculate the unloaded current gain $\frac{i_{out}}{i_s}$.

(e) Given $R_s = R_{in1}$ what is the value of R_L where $\frac{i_{out}}{i_s}$ is $\frac{1}{4}$ that calculated in part (d)?